International space station :
Canada's involvement

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THE INTERNATIONAL SPACE STATION: CANADA'S INVOLVEMENT

Lynne C. Myers
Science and Technology Division

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ISSUE DEFINITION

For many years, the United States has been actively, and generally successfully, involved in the exploration of space. It has sent unmanned and manned space craft into orbit and brought them back. It has landed men on the moon and seen them return safely to earth. The space shuttle has demonstrated the feasibility (and the dangers) of the reusable space craft. The U.S. National Aeronautics and Space Administration (NASA) views the construction and operation of a permanently manned space station as the critical next step in advancing human space exploration. The mission of the space station will be three-fold. First, it will provide an orbiting research base in which the effects of long stays in space on human physiology and well-being can be assessed. This information is essential if man is to continue to explore and exploit the space environment successfully. The second function will be as an advanced research laboratory in which we can begin to understand how to utilize the unique features of space - near-zero gravity, near-perfect vacuum and lack of atmospheric interference - to study new materials, new medicines and new technologies. Finally, the space station will be an engineering test-bed providing the opportunity to learn how to build, operate and maintain complex systems in space. In 1984, former President Reagan committed the United States to building the space station and invited Canada, Japan and the European Space Agency (ESA) to join in this ambitious program. At the Shamrock Summit in March 1986, former Prime Minister Brian Mulroney announced that Canada was accepting the invitation. The same year saw ESA and Japan agree to take part as well.

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* The original version of this Current Issue Review was published in February 1987; the paper has been regularly updated since that time.

The Canadian government agreed to develop, build and operate one of the station's mission-critical elements - the Mobile Servicing System (MSS), for assembly, maintenance and servicing tasks on the space station. **The MSS consists of a Mobile Base System, two manipulators (the RMS or Remote Manipulator System and the SPDM or Special Purpose Dextrous Manipulator) and the Canadian Space Vision System (CSVS).** The opportunity to build on our already well-established space industry, the potential for spin-offs from the advances in robotics and artificial intelligence engendered by this effort and future access to the space station for scientific research and manufacturing were cited as reasons for Canada's becoming involved. The estimated cost of Canadian participation was originally set at $800 million. Over the years this commitment grew to include some $1.9 billion by the year 2005. More recently, however, federal deficit reduction efforts have necessitated a decrease in the commitment. Following renegotiations after the 1994 budget, Canada reduced its financial commitment to $496 million in addition to the $713 million already contributed. This brings the total down to about $1.2 billion. As detailed elsewhere in this review, though reducing our financial input, Canada has retained those portions of the program with the greatest potential for economic and scientific benefit to Canadians.

BACKGROUND AND ANALYSIS

A. The Space Station

The U.S. space station will not be the world's first, since, in 1973-74, Skylab, which could house astronauts for up to three months at a time, was already in orbit above the earth. Between that time and the 1984 decision to build the space station, the U.S. concentrated on developing the Space Shuttle (or STS - space transportation system). In the meantime, the Soviet Salyut program has provided permanent, manned space station facilities since 1971. In operating the MIR space station for many years, the Soviets gained much valuable experience. After the breakup of the Soviet Union, the future of MIR was questioned, but it was able to keep operating. Beginning in May 1995, NASA planned to dock its space shuttles Atlantis and Discovery with the MIR Station as many as 10 times. This is part of the phase-in of Russian participation in the U.S. space station program.

As it was originally conceived, the U.S. space station program was ambitious and innovative. The station was expected to perform a wide range of functions, serving as:

- a laboratory in space, for scientific research and the development of new technologies;
- a permanent observatory, with elements in low inclination and polar orbits, from which to observe Earth and the universe;
- a transportation centre for stationing payloads and vehicles, processed and deployed to their destinations;
- a servicing facility for maintaining, repairing and refurbishing payloads and vehicles;
- an assembly facility for assembling and checking out large space structures and systems;
- a facility to enable manufacturing in space, where the unique environment enhances commercial opportunities;
- a storage depot to keep payloads and parts on orbit for subsequent use; and
- a staging base for possible future space projects, such as a permanent lunar base, a manned mission to Mars, a manned survey of the asteroids, a manned scientific and communications facility in geosynchronous orbit, or unmanned planetary probes.

In 1990, budget restrictions, along with some misgivings about the engineering of the proposed station, led Congress to order NASA to review its design and adjust the program. As a result, a smaller version of the space station became the official proposal. This 1990 redesign did not affect the MSS design and Canada proceeded according to the original criteria set out by NASA.

Over the years since its first approval, the U.S. Congress has not provided this project with as much funding as NASA had requested and expected. For example, in 1988 NASA asked for a total of $767 million, but Congress appropriated only $393 million. Subsequent years have seen a similar pattern, with one Congressional Committee in 1992 even voting to stop all funding for the space station; this funding was restored by the House of Representatives but at a level of $1.9 billion, rather than the $2.45 billion NASA had requested. Again in 1993 there were rumours that funding for the space station would be slashed or eliminated. Early in 1993,

however, the White House announced that it would be requesting $2.305 billion for the Space Station, for fiscal year 1994. President Clinton reaffirmed his support for the program, but at the same time ordered yet another redesign to cut costs further. Before this new design could be presented to the President for his approval, negotiations began with Russia, which wanted to contribute its expertise and hardware to the international space station. Again this year (1994), space station proponents have had to battle through the budget process in the U.S. Congress to keep the space station on track. Funding has now been approved for the next fiscal year and U.S. proponents hope that Congress will be less keen to cut this project as it reaches the construction phase. NASA's international partners also hope that further redesigns will not be required.

As the design has changed, so too have the official NASA program objectives for the space station, which are now more immediate, and perhaps less grandiose. The official objectives are now stated as follows:

- to establish a permanently manned multipurpose facility in low Earth orbit (LEO) in the 1990s;
- to enhance and evolve mankind's ability to live and work safely in space;
- to stimulate technologies of national importance by using them to provide space station capabilities;
- to provide long-term, cost-effective operation and utilization of continually improving facilities for scientific, technological, commercial and operational activities enabled or enhanced by the presence of man in space;
- to promote substantial international cooperation in space;
- to create and expand opportunities for private-sector activity in space;
- to provide for the evolution of the space station to meet future needs and challenges; and
- to foster public knowledge and understanding of the role of habitable space system capabilities in the evolution of human experience outside the Earth's atmosphere.

In its original design, the space station resembled a large rectangle of metal trusses. The trusses would have been taken into space by the shuttle and assembled on-site by the Canadian-made Mobile Servicing System (MSS). In the most recent redesign of the station, the truss will be

pre-integrated and tested, with all of its subsystems in place before launch. The Canadarm (or Remote Manipulator System), already in use onboard the space shuttle, will be used to connect the first three trusses. The MSS, designed and currently being built in Canada, will carry out the rest of the construction. The trusses will be connected from end to end and will be the backbone of the station. At either end of the structure will be the solar arrays, which will provide 110 kilowatts of power for the space station. Laboratory modules and habitation modules will be launched in later shuttle assembly flights and will be attached to the truss structure. To facilitate the movement of astronauts, the various modules will be connected by a series of nodes (spaces adjacent to, but not part of, the module - something like a vestibule).

The redesigned space station will be smaller than the original (108 m rather than 150 m) and will house four, rather than eight, astronauts. In addition, it will be capable of transmitting only about one sixth as much information per minute back to earth. Clearly, the range and number of experiments that can be carried out with this new configuration will be inferior to what was originally planned. However, from the Canadian point of view, these changes are not critical, since both the old and new design require the MSS.

Although plans and schedules are still in a state of flux, the latest information shows that NASA plans to launch the first elements of the space station in 1997 and to have it totally constructed by 2002. After just the first six assembly flights, the station will have reached what is called MTC or man-tended capability. This means that experiments could be set up by astronauts from the shuttle and then left in orbit until the next shuttle flight arrives. Once MTC is achieved, there will be four shuttle flights per year for station assembly and maintenance as well as three utilization flights each year. During the latter, the shuttle with its seven-person crew will dock with the station for about two weeks at a time; four of the crew will devote their time to carrying out experiments for space station users. A further 11 assembly flights will follow the MTC phase, with the station expected to achieve PMC, or permanently-manned capability, by the year 2002. After this time, the space station will be permanently manned by a four-member crew, two of whom will be dedicated to supporting space station user activities (i.e. carrying out experiments for users). The countries participating in the operation of the station will share those costs. They will have access to the time and space in the laboratories in proportion to their contribution; The United States will have a 71.7% share; Japan and the European Space Agency will have 12.8% each; and Canada will have 2.3%.

B. Canada's Space Station Program

1. Program Objectives: Why Should Canada Participate?

The answer to this question is not simple. Among the many reasons put forward to justify Canadian participation in this ambitious space program are achieving international prestige as a technologically advanced industrial economy, securing an entrée into important new high-tech fields, generating technological spin-offs on earth, buying long-term access to the space environment for Canadian researchers, and developing a highly qualified work-force in the fields of robotics and automation. In the short term, the technical and economic spin-offs on earth are arguably the most significant goals, together with the creation of a pool of knowledgeable scientists and industrialists in several emerging technological fields. Officials of the Canadian Space Agency point out that more than $1 billion in business activity directly related to the Space Station has already flowed to Canadian companies, and that this figure is expected to surpass $5 billion over the next 20 to 25 years. Many of the technologies developed for the space station, especially in the fields of robotics and automation, will have terrestrial applications, including work in "hostile" environments such as the nuclear industry, mining and offshore resource development.

In a 1986 report, the Canadian Institute for Advanced Research discussed Canada's participation in the following terms:

> Participation in the Space Station is analogous to joining a fitness club - an economic fitness club. Agreement to provide a component of the Station is the membership fee. If Canada is going to get any tangible benefit from being in the club, though, it must have the ability and the financial resources to use the facilities. Equally important, it will need to use its newly acquired strength and agility in all aspects of its economic life. If it does not, the membership fee will be wasted.

This report cautioned, however, that resources must be put into all aspects of our space effort if maximum benefit is to be derived. To achieve this, it suggested that our space station program be viewed as having several important essential elements, namely:

- production and operation of the Mobile Servicing System (MSS);
- a Space Station user support program;

- a technology development program; and
- a technology exploitation program.

If all four elements were effectively supported, the report predicted that Canada could benefit considerably from its investment, as it evolves into a knowledge-based economy. They felt that the program would:

- stimulate and partially finance the creation of a long-term applied research base within Canadian industry;
- facilitate emergence of new, knowledge-intensive industries, an important factor in Canada's economic development;
- assist in the creation of a pool of highly skilled researchers, whose expertise would contribute to technological development; and
- promote the establishment of productive long-term relationships between industry and universities.

The current CSSP (Canadian Space Station Program) has held close to these earlier suggestions and to the original objectives. In 1991, the Space Station Program Office of the Canadian Space Agency detailed the program objectives as follows:

1. To enhance Canada's ability to operate in space and to exploit space by:

- developing and operating the MSS to play a predominant role in assembling and maintaining Space Station;
- developing and applying strategic technologies for the MSS, particularly in the fields of automation and robotics;
- facilitating participation in Space Station use by Canadian industry, government, and university sectors;
- assuming Canada's share of Space Station common operations;
- developing user demonstration experiments emphasizing technologies with commercial potential; and
- participating in the international management of the Space Station.

2. To maximize social and economic benefits to Canadians by:

   - improving regional distribution of space-related government expenditures; and
   - fostering commercialization of Space Station technologies.

In 1991, the Canadian program had four major components, namely:

1. Development and operations of the MSS. This was to be Canada's main contribution to the Space Station, to include a platform, a Remote Manipulator System, and a Special Purpose Dextrous manipulator; MSS operations included sophisticated ground-based facilities for simulating operations planning;

2. Operation of the Space Station. This task was to consist of Canada's contribution to the operations and maintenance of the Space Station, once launched, with the help of Canadian Astronauts;

3. The Strategic Technologies in Automation and Robotics (STEAR) program, which consisted of contracts to industry to develop next generation technologies for the continued upgrading and evolution of the MSS; and

4. The user Development Program (UDP) to foster, through contracts with firms and universities, the Canadian use and commercial exploitation of Space Station, in particular microgravity, through development of new materials, products and processes in space.

This program has changed somewhat, particularly with respect to Items 1 and 2, as a result of the renegotiation of Canadian participation following the 1994 budget. In Item 1, Canada was planning to design and build both the MSS and the SPDM (Special Purpose Dextrous Manipulator). Under the new agreement we will still complete design and construction of the MSS, as well as retaining responsibility for its operation once on the station. We will, however, complete only the design, and not the construction, of the SPDM at this time. This will yield savings of some $393 million. Canada was given an additional three years to make the decision on construction of SPDM. The CSA feels that the new program retains the most important elements of the old since it allows Canadian scientists and companies to continue developing their design expertise in the important automation and robotics fields.

The revolutionary CSVS (Canadian Space Vision System) is being developed in a cooperative program between the Canadian Space Agency and NASA. It is designed to

provide the station's robotic arms with "synthetic visual cues," so they can "see" what they are doing. The CSVS began on-orbit testing during a 1992 space shuttle flight. In November 1995, an advanced version was flown on a mission, during which it was used in a docking operation in the cargo bay of the space shuttle.

The second major change to Canada's participation in the space station is that our commitment to participate in the ongoing operation of the Space Station (Item 2) has been dropped completely, for a savings over ten years of approximately $270 million. Although Canada has deferred using its share of Space Station resources, we still have the option of allowing Canadian scientists access to the station on a case-by-case, pay-as-you-go basis. Canadian astronauts have been assured of one flight per year until construction of the station is complete. After that time foreign astronauts will undertake the experiments sent to the station by Canadian researchers. By not using our share of the station resources (2.3%) on a regular basis, we are saving another $75 million.

It might appear that giving up the regular use of the Space Station negates our reason for becoming involved in the first place. Officials at the CSA, however, insist that the most economic and technological gains for Canada will be realized by the research and development and industrial activity resulting from the design and/or construction of MSS and the SPDM. The fact that $1 billion in benefits have already been realized from the $713 million government investment would seem to lend credence to this claim. In addition, our space scientists will still have access to the station, albeit on slightly different terms from those previously envisioned. The following sections look briefly at the individual elements of the Space Station Program.

2. The Mobile Servicing System (MSS)

In the past, Canada contributed to the U.S. space program with the very successful Canadarm, which now flies on almost every space shuttle flight. When asked to join in the space station program, it was logical for Canada to build on this expertise, but Canada insisted that our participation entail more than the provision of a piece of hardware since we wanted to ensure that our involvement would continue after the station became operational. The U.S. concurred and Canada agreed to design, build and operate the MSS. It is worth noting that Canada is the only

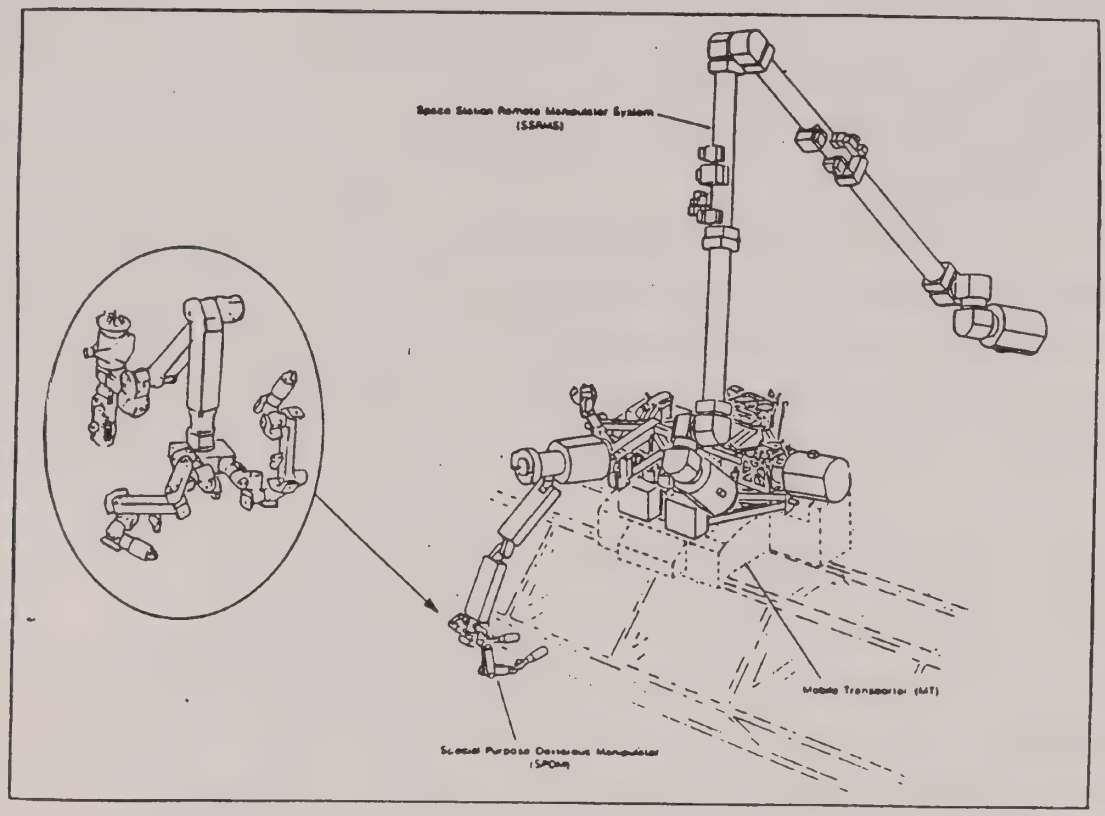
foreign country supplying what is known as a mission-critical element of the station, one that must operate on time and in the prescribed fashion in order for the mission to continue.

Figure 1 presents an artist's impression of the design of the MSS. This system will play the main role in the assembly and maintenance of the space station, moving equipment and supplies around the station, supporting astronauts during EVAs (extra vehicular activities), and servicing instruments and other payloads attached to the station. In addition, the MSS will be used for docking the visiting space shuttles and for loading and unloading the shuttle cargo bay. Canada is responsible for the total design, development and long-term operation of the MSS.

As can be seen in Figure 1, the MSS consists of two main elements. The first is the RMS or remote manipulator system, which represents the next generation of the Canadarm now flying on the four space shuttles. The arm will be 17.6 m (58 feet) long and have a payload capacity of 116,000 kg (128 tons). It will move along the truss structure of the station on a mobile transporter, which will be provided by the United States. The MSS is also designed to accommodate a second, smaller robot known as the SPDM or special purpose dextrous manipulator. This robot (known affectionately by its developers as "Hector the Erector") will have two arms, each about 2 m (6.65 ft) long, and remarkable mechanical dexterity to enable it to undertake more delicate jobs such as working on electrical circuits, fuel lines and cooling systems.

Advances in robotics, vision systems and artificial intelligence have provided the SPDM with very human-like senses. For example, the SPDM will have three separate cameras which allow it to "see" its way around the station. It can recognize targets and adjust its own position in response. Sophisticated software programs also prevent the two arms from colliding with one another, and automatically keep the elbow from hitting anything, or anyone, when the arms are reaching to grapple a target. In addition to seeing, with the help of the space vision system, this robot can also "feel." It is equipped with force-sensing systems which tell it just how hard it is touching, pushing, pulling or twisting something. Given this ability, the robot can be used to repair and/or replace delicate electronic parts or tighten bolts without risk of stripping them. These abilities will relieve astronauts of the necessity to go out into space to undertake routine repairs. As already noted, Canada has deferred for three years a decision on whether to construct the SPDM, or only to complete its design.

Figure 1
Space Station Mobile Servicing System
and Special Purpose Dextrous Manipulator



Source: Technical and Administrative Services. NASA. *Space Station Freedom Media Handbook*, p. 78.

The RMS and SPDM are designed for a lifetime greater than ten years, and must withstand the stresses of prolonged exposure in space with maximum reliability. Canada's success in meeting the stringent demands for the Canadarm led NASA to entrust us with the RMS and SPDM development. The industrial team responsible for most of the RMS and SPDM components reflects the goal of spreading the government space-related expenditures throughout the country. The team is headed by Spar Aerospace (based in Montreal and Toronto). The others are IMP

Group (Halifax), CAE Electronics (Montreal), CAL Corporation (Ottawa), SED Systems (Saskatoon) and MacDonald Dettwiler Associates (Richmond, BC).

3. The Strategic Technologies in Automation and Robotics (STEAR) Program

The STEAR program is designed to allow for the continued development and integration of new technologies into the MSS during its expected 30-year mission. The goal is to ensure that the MSS does not become obsolete. Because all these new technologies will have to meet space qualifications, their development will be lengthy and many of the first applications are likely to be terrestrial spin-offs.

The advanced, strategic technologies being supported by STEAR via contracts to industry include automation of operations and expert systems, health monitoring and automated power management, autonomous robotics, enhanced space vision systems, trajectory planning and object avoidance (keeping the SPDM from colliding with other things), and the protection of materials in the space environment.

4. The User Development Program (UDP)

To make full use of the unique microgravity environment to be offered by the Space Station, Canada needs to develop a group of scientists expert in this area. The UDP has responsibility for this program, which has three areas of focus. The first is understanding space itself. This involves developing experts in space physics and upper atmosphere physics and chemistry, areas in which Canadians have long excelled. The second focus is on microgravity science, which takes advantage of the unique characteristics of a gravity-free environment. The third focus is on using the station for observations from space, both space astronomy and earth observation. The renegotiation of our participation in the U.S. Space Station program should affect potential end-users only to the extent that foreign, rather than Canadian astronauts will be handling the space activities.

C. Other International Contributions

1. The Japanese Experimental Module (JEM)

Japan, like Canada, is proposing to participate in the space station project. Its contribution will be a laboratory to accommodate general scientific and technology development research activities including microgravity studies. The JEM will have a pressurized module, which would be a 10-m long tube with a 4.2-m diameter. There will also be a smaller exposed facility, and an airlock joining those first two elements, as well as a local remote manipulator and an experiment logistics module (ELM). The ELM attaches to the laboratory and can be removed, returned to earth to deliver experiments and products made in space, refilled with new materials and supplies and returned to the station to be reattached to the JEM. The JEM itself attaches to the basic truss framework of the station. The ELM is being made compatible with Japan's own launch vehicle, the H-2, which is expected to be ready for use in the mid-1990s. Japan has agreed to spend about $2 billion on its space station contribution.

2. The European Space Agency's Pressurized Module (ESA Module)

The European Space Agency is developing an attached, pressurized, multi-purpose laboratory as its contribution to the space station. This facility which will be almost 12 m long, with a diameter of 4.5 m will be permanently attached to the space station. It is designed for international use principally in the fields of fluid physics, life sciences research and materials research. The module will provide a shirt-sleeve environment in which scientists can work. In accord with international agreement, 46% of the space is reserved for U.S. experiments and 3% for Canadian.

Like the JEM and the U.S. laboratory and habitation modules, the ESA module will include storage capacity and accommodation for what is known as "crew safe-haven capability." In other words, in the event of an emergency, there would be sufficient supplies and accommodation for the space station crew to await rescue.

CHRONOLOGY

20 May 1982 - The Space Station Task Force was set up at NASA to identify mission requirements, define the space station concept and coordinate NASA research centres interested in the concept.

July-August 1982 - NASA contracted with aerospace firms to identify user requirements in space science, technology development commercial activities and, initially, national security. Canada, Japan and ESA countries did similar independent reviews.

25 January 1984 - The President announced that the U.S. would have a permanently-manned space station by the end of the decade.

18 March 1986 - Prime Minister Mulroney announced Canada's acceptance of the invitation to participate in the space station program.

16 January 1987 - External Affairs Minister, the Right Honourable Joseph Clark, sent a letter to the U.S. administration expressing Canada's concern over reports that the U.S. military wanted to use the space station for military experiments.

December 1987 - Canadian and U.S. negotiators agreed on the text of a Memorandum of Understanding governing Canadian participation in the Space Station Project. It was finalized after Cabinet and Congressional approval early in 1988.

21 April 1988 - The Ministers of Regional Industrial Expansion and Science and Technology (Mr. de Cotret) and Science and Technology (Mr. Oberle) announced the government's decision to commit $1.2 billion over 15 years to the realization of the Mobile Servicing System (MSS) for the U.S. Space Station.

29 September 1988 - An international agreement governing the construction and operation of the Space Station was reached by the USA, Japan, Canada and the European Space Agency. Although Canada has not signed the agreement, it has agreed to respect its spirit.

1 March 1989 - The federal government announced the creation of a national space agency. The Space Station Management Program formerly part of the National Research Council, will fall within the mandate of the Canadian Space Agency.

10 May 1990 - Bill C-16; An Act to establish the Canadian Space Agency and other matters in relation to space, was given Royal Assent.

October 1990 - Congress cut the NASA Space Station budget and ordered a review of the entire program. This review resulted in important design and scheduling changes.

June 1994 - Canada announced that it would reduce its financial commitment to the operation of the Station, while continuing with the design, construction and operation of the MSS.

August 1994 - A redesigned Space Station, with probable Russian participation, received U.S. Congressional approval. Construction of Station components was now underway.

November 1995 - An advanced version of the Canadian Space Vision System flew on a space shuttle mission and was used in a docking exercise.

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